General Introduction

Biofluid mechanics is the study of certain class of biological problems from fluid mechanics point of view. It does not involve any new development of the general principles of fluid mechanics but it involves some new applications of the method of fluid mechanics. Complex movements of fluids in the biological system demand for their analysis. In 1839, the engineer Hagen studied the water flow through brass tubes. Consequently, Poiseuille (1799-1869) was a French physician who first investigated in a quantitative manner the flow of water through glass tube. Poiseuille’s interest was the flow of blood through the vessels of the circulatory system, but worked with water because of the difficulty at the time of preventing blood from clotting on exposure to air. Humphrey (2003) defined the biomechanics as the development, extension and application of mechanics for the purposes of understanding better physiology and pathophysiology as well as the diagnosis and treatment of disease and injury.

Biofluids

The fluids present in the ducts of a living body are called biofluids. Biofluid mechanics describe the kinematics and dynamics of body fluids in human beings, animals and plants. Modern biofluid mechanics measures and analyses the flow in the blood vessels, the respiratory system, the lymphatic system and many other physiological situations. Biofluid mechanics factors are taken into consideration in
the clinical areas such as artificial organ and vessel development, urological measurements, artificial urethra, shock wave treatment of kidney stones, mass and material transport through membranes and the influence of fluid flow around living bodies. Many applications on general biofluid mechanism have been reported in reviews by Liepsch (2002) and Van De Vosse (2003).

Classification of fluids

(i) Newtonian Fluid

If shear stress is linearly proportional to the rate of strain, the fluid is called as a Newtonian fluid. Newtonian behaviour has been observed in all gases in liquids or solutions of materials of low molecular weight.

The constitute equation for Newtonian fluid is

\[ \tau = \mu \dot{\gamma} \]

where \( \tau \) is the stress, \( \dot{\gamma} \) is the shear rate and \( \mu \) is the viscosity of the fluid.

(ii) Non-Newtonian Fluid

Non-Newtonian fluids generally exhibit a nonlinear relationship between stress and shear rate. Foodstuffs (like banana juice, apple juice, chyme), blood, slurries, sperm, intra uterine fluid, etc. are behaves like a non-Newtonian fluids.

Peristaltic Transport

The word peristalsis stems from the Greek word Peristaltikos, which means clasp and compressing. Peristaltic pumping is a form of fluid transport
generated in the fluid contained in a distensible tube when a progressive wave travels along the wall of the tube. It is an inherent property of many syncytial smooth muscle tubes; stimulation at any point can cause a contractile ring to appear in the circular muscle of the gut, and this ring then spreads along the tube. In such a way, peristalsis occurs in the gastrointestinal tract, the bile ducts, other glandular ducts throughout the body, the ureters, and many other smooth muscle tubes of the body, Guyton and Hall (2003).

**Literature survey**

Peristaltic pumping is the one of mechanism pumping of fluids from one place to another in various ducts due to the active muscular contraction and expansion of the wall. The first attempt to study the fluid dynamics aspects of peristaltic transport with an experimental investigation is by Latham (1966). At the same time Burns and Parkes (1967) gave a perturbation solution to the mathematical formulation of peristaltic transport through a pipe and a channel, in powers of the amplitude ratio. Barton and Raynor (1968) have discussed the corresponding axisymmetric case. A contemporary investigation was reported by Shapiro (1967) for two-dimensional peristaltic pumping under conditions that the appropriate Reynolds number is so small that the flow may be considered inertia--free and the length of the peristaltic wave is very long compared to the width of the tube. Asymptotic solutions for the axisymmetric peristaltic transport in terms of the ratio of the small amplitude to the mean radius was given by Yin and Fung.
(1969) for a finite range of Reynolds number and wavelength, following the analysis of Fung and Yih (1968) in two dimensional channel case. The small amplitude assumption has been relaxed under infinite wavelength approximation by Shapiro et al. (1969). Complete reviews on peristaltic pumping have been given by Jaffrin and Shapiro (1971) and in a book by Rath (1980). The experimental verification of these models by Weinberg et al. (1971) confirmed that the Lagrangian approach should be used to obtain the criterion for the backward leakage of fluid particles with long wave approximation.

The peristaltic flow in a tapered channel and tube was first investigation by Gupta and Seshadri (1976). Following their analysis many other peristaltic flow problems are reported by Srivastava et al. (1983) and Mekheimer (2002). An asymptotic theory for the peristaltic transport in a flexible tube of arbitrary cross section has been developed by Shen (1976). He presented the velocity components for an elliptic tube, under small and finite amplitude assumptions. The influence of waveform on peristaltic transport of a Newtonian fluid was examined by Mahrenholtz et al. (1978) for high Reynolds number in a highly occluded channel. The peristaltic flow due to the propagation of lateral bending waves along the channel walls has been investigated by Wilson and Panton (1979) and Wilson et al. (1979). Rath (1982) was investigated the peristaltic flow through a lobe-shaped tube under zero Reynolds number and long-wave length approximations. Hason et al. (1984) discussed the peristaltic pumping in three different waveforms, namely triangular, trapezoidal and square wave, with the
applications to the flow of spermatic fluid in human vas deferens and that of rhesus monkey. The peristaltic transport in a tapered tube using the perturbation analysis with small amplitude has been studied by Misra and Pandey (1995). Usha and Ramachandra Rao (1995) have studied the peristaltic transport of a biofluid in a pipe of elliptic cross section. The single wave peristaltic flow of tear-drop shape was investigated by Tadjfar et al. (2000).

Several researchers considered the fluid to behave like a Newtonian fluid for physiological peristalsis including the flow of blood in arterioles. But such a model cannot be suitable for blood flow unless the non-Newtonian nature of the fluid is included in it. A theoretical investigation for blood flow by considering blood as a non-Newtonian power-law fluid was reported by Raju and Devanathan (1972). They employed the perturbation technique used by Chow (1970) to solve the model of the flow in a cylindrical tube with a sinusoidal wave of small amplitude. Later Girija Devi and Devanathan (1975) extended the same problem to replace power-law nature of the fluid by micro polar nature. Consequently a similar solution for viscoelastic liquids was studied by Bohme and Friedrich (1983). Also they discussed mechanical efficiency of pumping for such liquids. Peristaltic flow of non-Newtonian fluids containing small spherical particles has been discussed by Rath and Reese (1984). Shukla and Gupta (1982) was studied the peristaltic transport of a power-law fluid with variable consistency. Peristaltic transport of non-Newtonian fluids with the application to the vas deferens and small intestine was studied by Srivastava and Srivastava
Consequently; peristaltic transport of power law fluid has been discussed by Srivastava & Srivastava (1988) with the application to the ductus deferens of the reproductive tract. The non-Newtonian peristaltic flow using a constitutive equation for a second order fluid has been investigated by Siddiqui et al. (1991) for a planar channel and by Siddiqui and Schwarz (1994) for an axisymmetric tube. They have performed a perturbation analysis with a wave number, including curvature and inertia effects and have determined range of validity of their perturbation solutions. The effects of third order fluid on peristaltic transport in a planar channel were studied by Siddiqui et al. (1993) and the corresponding axisymmetric tube results are obtained by Hayat et al. (2002). The non-Newtonian effects of Maxwel fluid on peristaltic transport have been discussed by Tsiklauri and Beresnev (2001). Abd El Naby and El Misiery (2002) investigate peristaltic transport of Carreau fluid in a tube, while Johnson – segalman fluid has been used for study by Hayat et al. (2003). Hayat et al. (2004) have discussed the effects of an oldroyd-B fluid on the peristaltic mechanism. The effect of an endoscope on the peristaltic flow of a Jeffrey fluid was studied by Hayat et al. (2006). Hayat et al. (2007) analyzed the peristaltic pumping of a Jeffrey fluid in an axisymmetric tube.

Provost and Schwarz (1994) have observed an interesting phenomenon in the free pumping region for a certain non-Newtonian (Riener-Philippoff) fluid model that the mean flow rate is zero or negative for a straight section dominated
(SSD) expansion or contraction waves. Also, Ramachandra Rao and Mishra (2004) have observed a negative mean flow rate is achieved under free pumping for a shear thickening fluid with SSD expansion wave and the same is observed for a SSD contraction wave in the case a shear thinning fluid. Whereas Srinivasacharya et al. (2003) have observed for a micropolar fluid that the time mean flow rate is always positive for all favorable pressure differences for a SSD expansion or contraction waves.


The magnetohydrodynamic (MHD) flow of a fluid in a channel with elastic, rhythmically contracting walls (peristaltic flow) is of interest in connection with certain problems of the movement of conductive physiological fluids, e.g., the blood and blood pump machines, and with the need for theoretical research on the operation of a peristaltic MHD compressor. The effect of moving magnetic field
on blood flow was studied by Sud et al. (1977), and they observed that the effect of suitable moving magnetic field accelerates the speed of blood. Srivastava and Agrawal (1980) considered the blood as an electrically conducting fluid and constitute a suspension of red cell in plasma. Also, Agrawal and Anwaruddin (1984) studied the effect of magnetic field on blood flow by taking a simple mathematical model for blood through an equally branched channel with flexible walls executing peristaltic waves using long wavelength approximation method and observed, for the flow of blood in arteries with arterial disease like arterial stenosis or arteriosclerosis, that the influence of magnetic field may be utilized as a blood pump in carrying out cardiac operations. El-Shehawey and Husseny (2002) studied peristaltic transport of a magneto-fluid with porous boundaries. It has been noticed that the mean axial velocity and the reversal flow decrease by increasing the magnetic parameter. Abd El Hakeem et al. (2003) discussed peristaltic flow of an incompressible Newtonian fluid with variable viscosity subject to a constant transverse magnetic field. They notice that the increasing magnetic field increases pressure rise. Mekheimer (2004) studied peristaltic flow of blood under the influence of a magnetic field in non-uniform channels. Recently, Abd El Hakeem et al. (2006) investigated peristaltic transport of a non-Newtonian fluid through a uniform tube subject to a constant transverse magnetic field. Hayat et al. (2007) have investigated the peristaltic flow of a third order fluid under the effect of a magnetic field in a planar channel. Hayat et al. (2007) have studied the non linear peristaltic flow of a fourth grade fluid in a planar channel.
under the effect of a magnetic field. Hayat et al. (2008) have discussed the peristaltic flow of a Jeffrey fluid under the effect of a magnetic field in a circular tube.

Flow through a porous medium has been of significant interest in recent years particularly among geophysical fluid dynamicists. Examples of natural porous media are beach sand, sandstone, limestone, rye bread, wood, the human lung, bileduct, gall bladder with stones and in small blood vessels. The first study of peristaltic flow through a porous medium is presented by Elsehawey et al., (1999). The interaction of peristaltic flow with pulsatile fluid under the effect of a transverse magnetic field through a porous medium bounded by a two-dimensional channel is studied by Afifi and Gad (2001). Mekheimer and Arabi (2003) studied the non-linear peristaltic transport of MHD flow through a porous medium. Non-linear peristaltic transport through a porous medium in an inclined planar channel has studied by Mekheimer (2003) taking into account the gravity effect on pumping characteristics. Afifi and Gad (2003) have studied the interaction of peristaltic flow with pulsatile fluid through a porous medium. The peristaltic transport of a Maxwell fluid though a porous medium with Hall effects was investigated by Hayat et al. (2007).